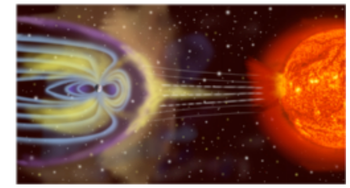
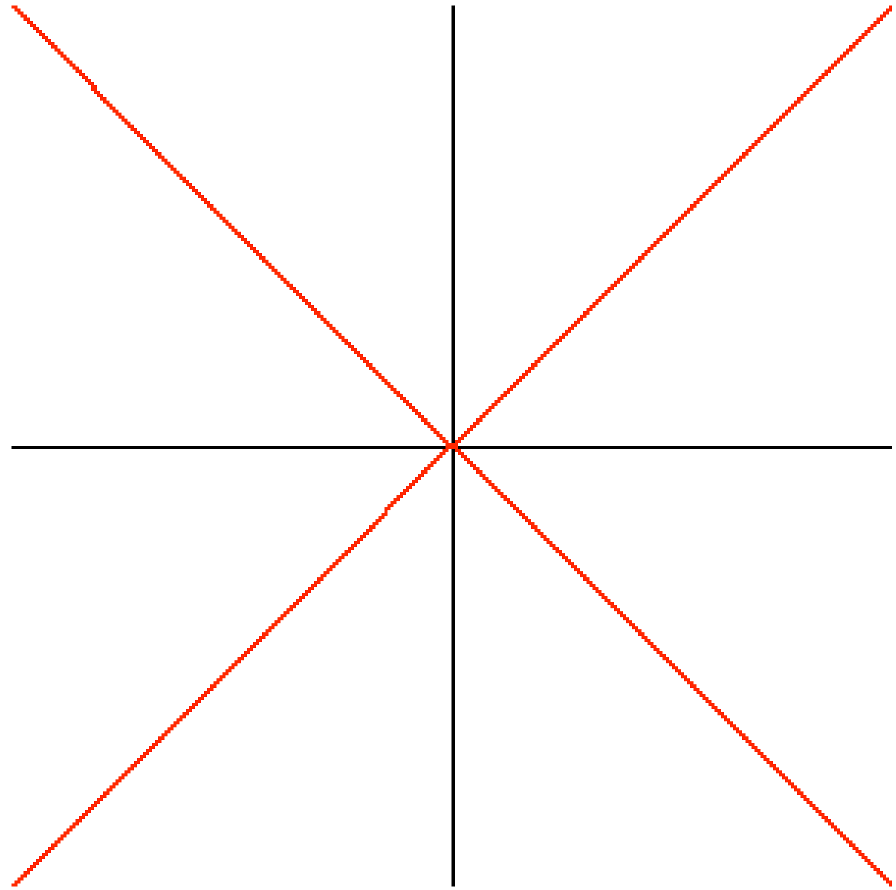
Footprints of Dayside Reconnexion

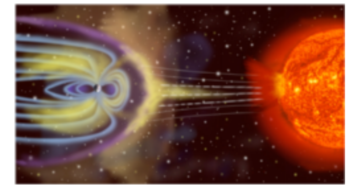


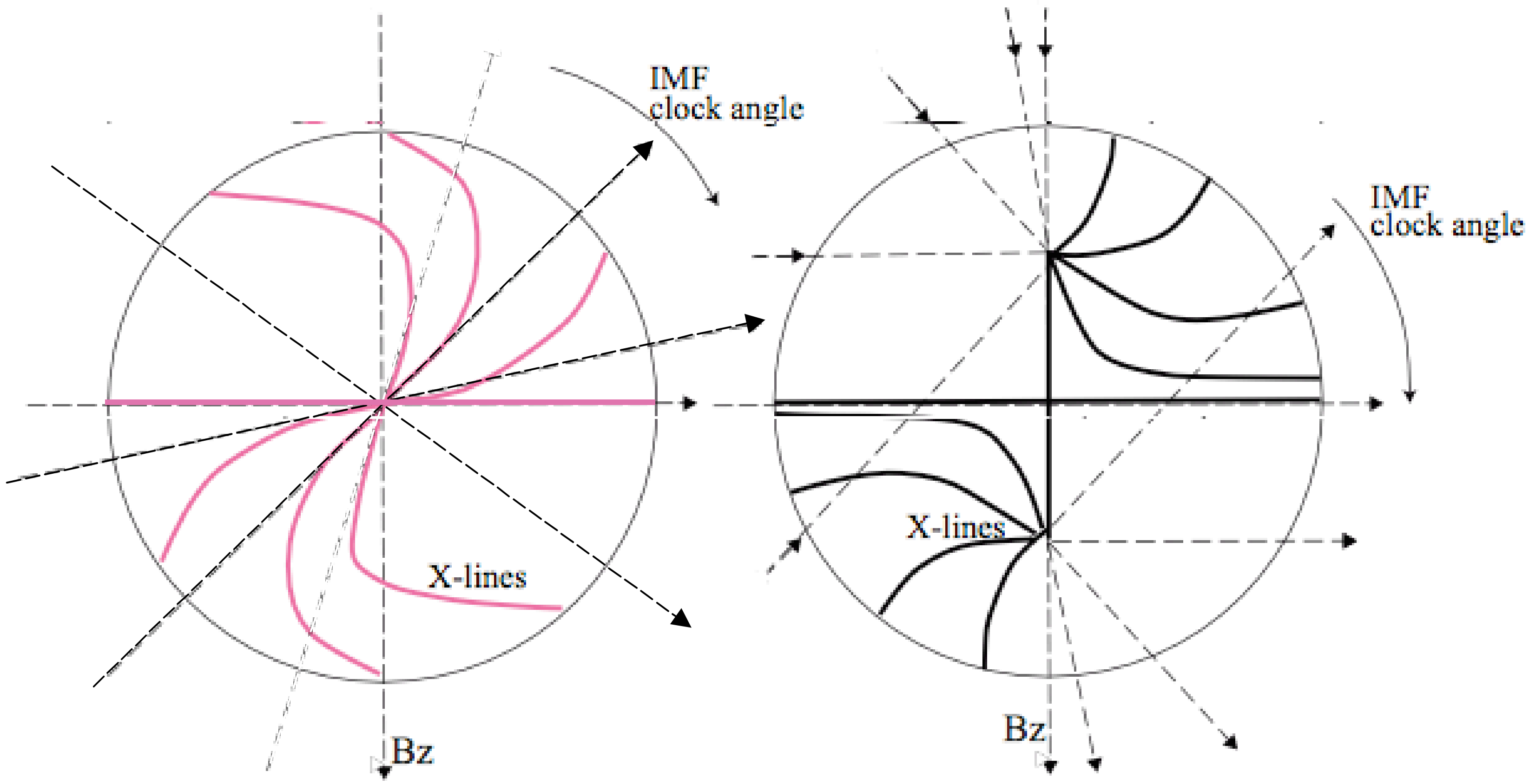
T. E. Moore(1), M.-C. Fok(1), M. O. Chandler(2), Chen(3), O. L. Vaisberg(4);
1. GSFC, Greenbelt, MD USA; 2. MSFC, Huntsville, AL USA; 3. USRA, Greenbelt, MD USA; 4. IKI, Moscow, Russia

- Outline
  - Component vs Antiparallel
  - Transpolar potential
  - Antiparallel Reconnexion
  - XL orientation problem
  - Component reconnexion
  - Reconnexion experiments
  - Reconnexion simulations
  - XL as Z or S line
  - Helical flux ropes
  - Cusp footprints
  - Q aurora
  - Conclusions



Component vs Antiparallel



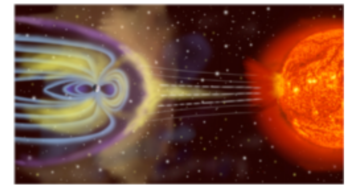


component reconnection **antiparallel reconnection**

Gonzalez & Mozer 1974, Cowley 1976
Moore et al., 2001

Crooker, 1979; Luhmann, 1984

TransPolar Potential (Component)



- Component reconnexion geometry seen from the sur
- Gonzalez and Mozer [1974 JGR]

GONZALEZ AND MOZER: A QUANTITATIVE RECONNECTION MODEL

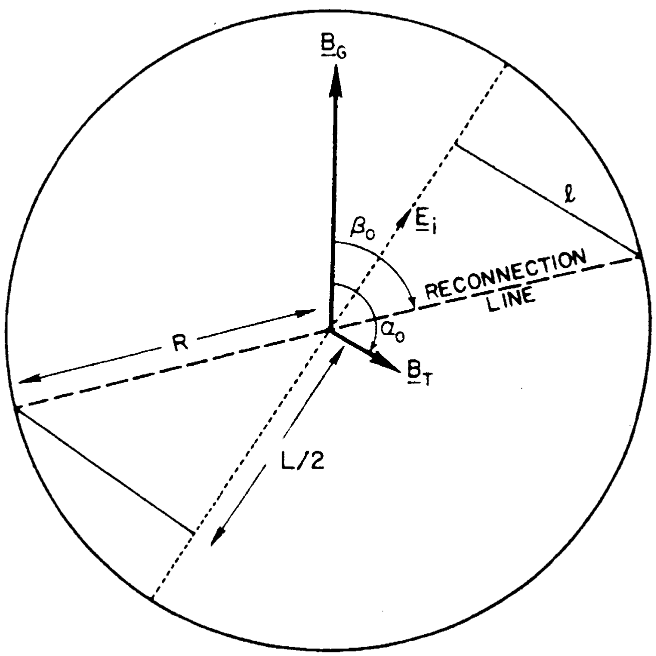


Fig. 5. Reconnection geometry as viewed from the sun.

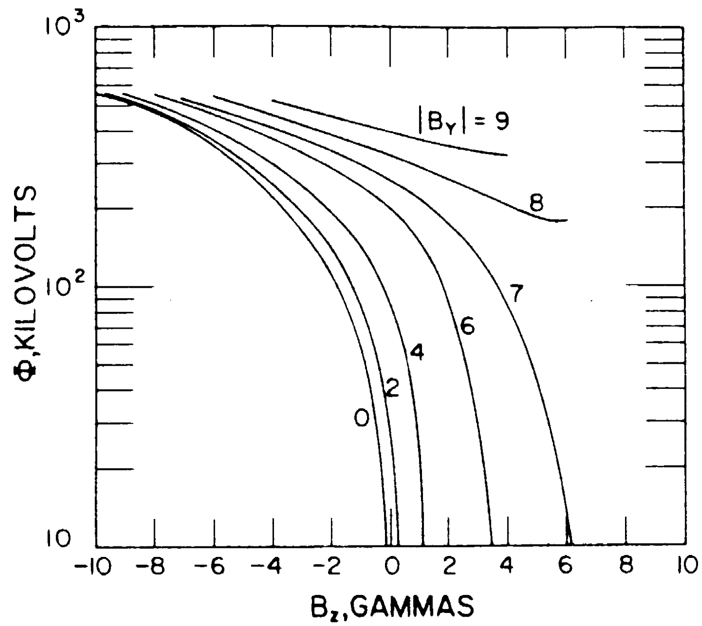
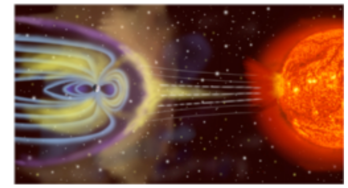
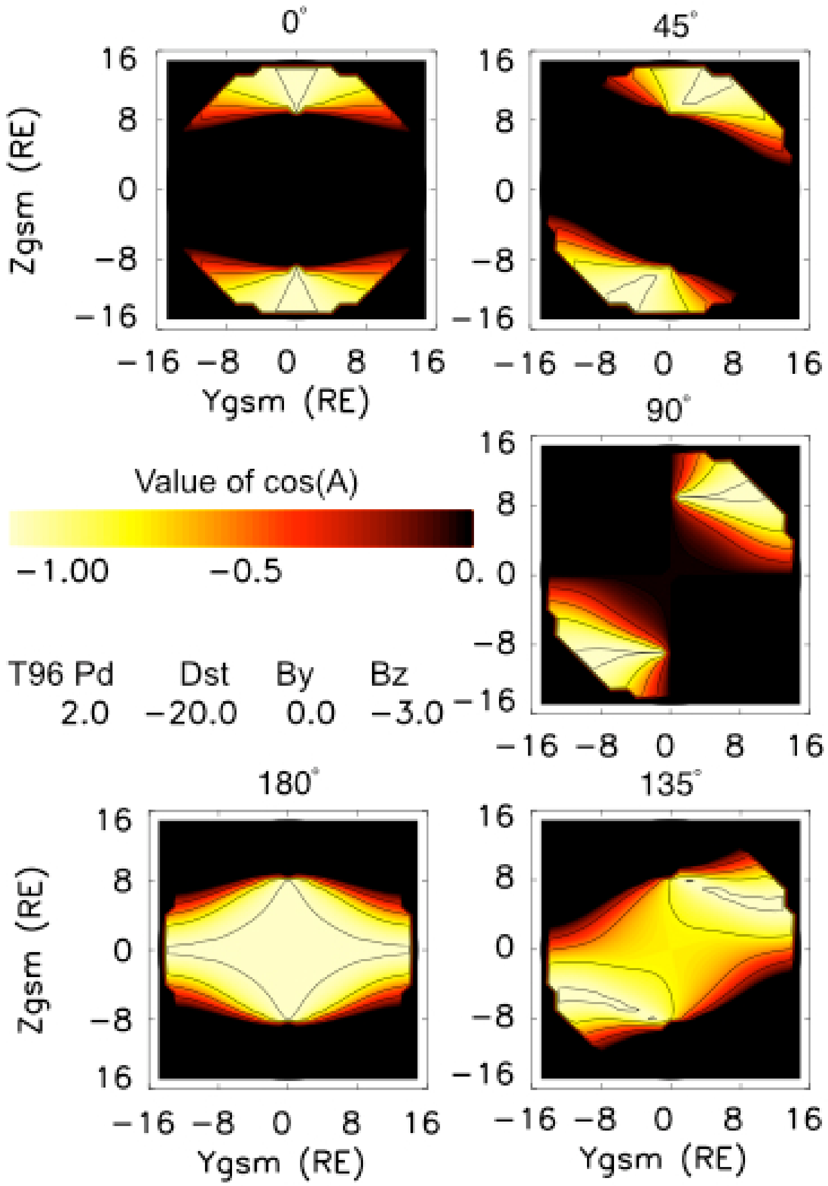


Fig. 8. Electric potential curves for a range of values of the Y and Z components of the interplanetary magnetic field. For the best agreement with the experiment, the model potential should be multiplied by 0.35.

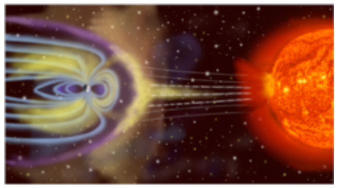
Antiparallel Reconnexion Sites



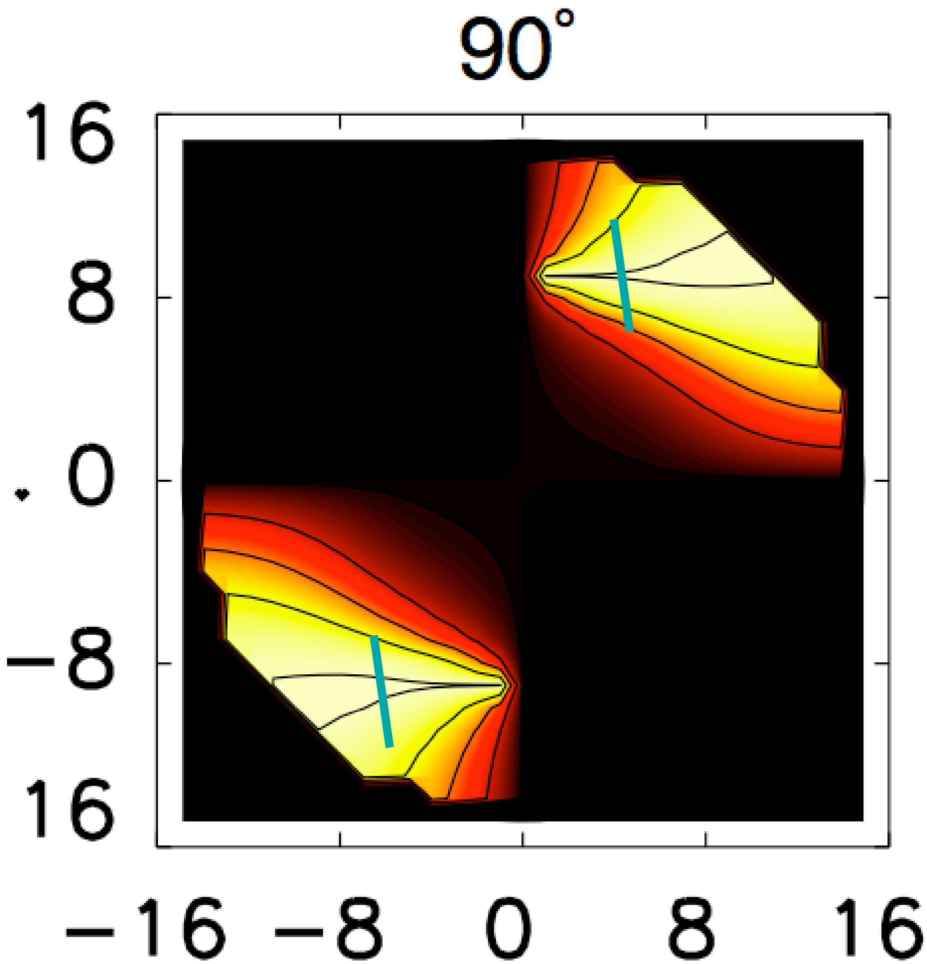


- Luhman et al. '84, following Crooker's proposal, computed a measure of alignment, cos(A)
- Reproducing that work here
  - T96 model, evaluated 0.5 Re inside the m'pause
  - draped magnetosheath field
- Antiparallel ridges radiate from the cusp ~ parallel to local field near cusp
- How is the X-line oriented?

XL Orientation Problem

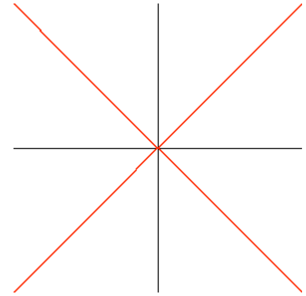


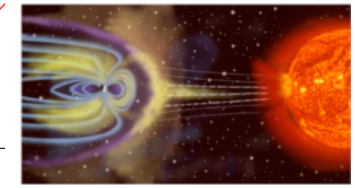
- Contours of cos(A):



- The X-line in general makes ~ right angle with the anti-parallel ridge
- Extends rapidly into regions that are non-anti-parallel
- Result:
  - If rate drops with cos(A):
  - Short X-line
  - Small potential drop?

Reconnexion Requirements

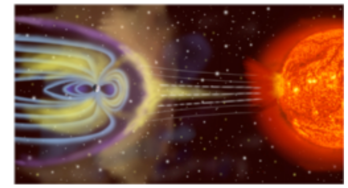




- Point:
  - Particles must “thaw” to jump from incoming to outgoing field lines (?)
  - They have to be "demagnetized" to do this (move with a finite gyro-radius motion)
  - Guide field prevents total |B| from dipping near the X-line
  - Guide field suppresses demagnetization of e-, stops reconnexion
  - Reconnexion localized to anti-parallel regions

- Counterpoint:
  - Plasmas **E**x**B** drift across fixed field lines
    - Vasyliunas ‘72; non-uniqueness of field line motion)
  - Plasmas move per pressure gradient and **J**x**B**
  - **E** generated by plasma **V**
  - Demagnetization gives necessary current flow (differential e-/i+ drift)
    - Guide field weakens **J**x**B**, potentially shorts **E//**?
  - Reconnexion widespread along XL that extends away from initiation sites

2.5D Reconnexion Simulations



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March 2001 JGR

Alfvénic collisionless magnetic reconnection and the Hall term

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Institute for Plasma Research, University of Maryland, College Park

R. E. Denton

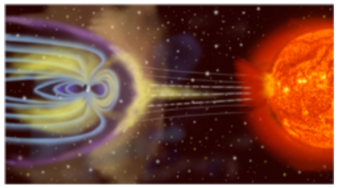
Department of Physics and Astronomy, Dartmouth College, Hanover,

al., 1995; *Drake*, 1995]. Although initial results indicate that the presence of a guide field does not slow the reconnection rate significantly [*Kleva et al.*, 1995; *Pritchett*, this issue], a thorough investigation needs to be done.

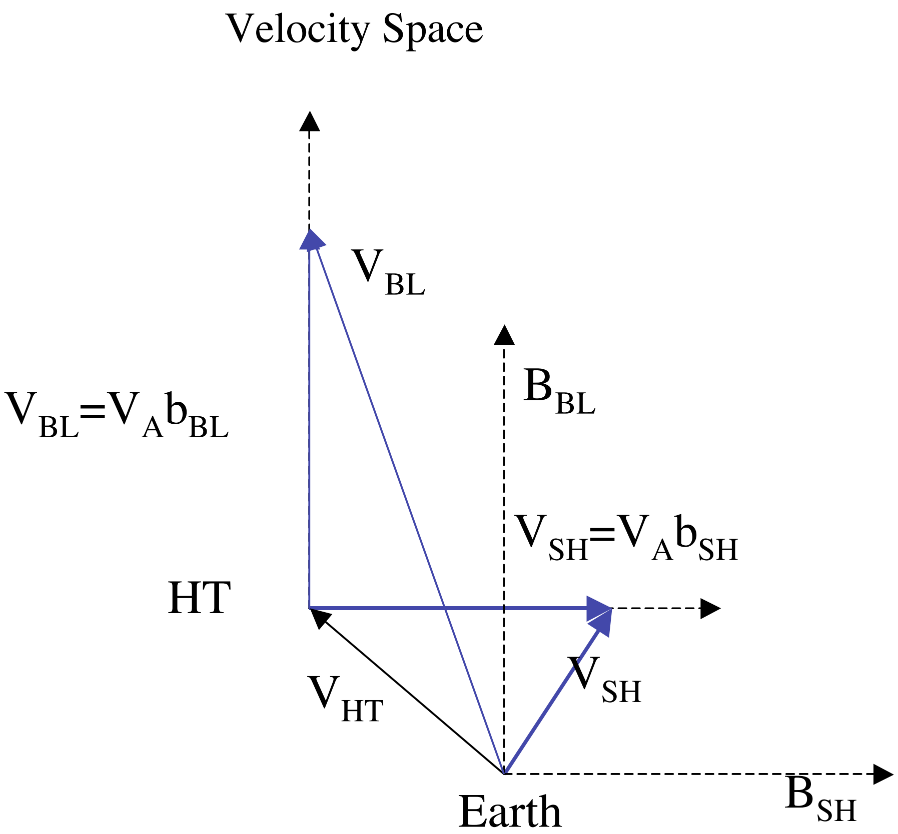
Abstract. The Geospace Environment Modeling (GEM) Challenge Harris current sheet problem is simulated in 2 1/2 dimensions using full particle, hybrid, and Hall MHD simulations. The same gross reconnection rate is found in all of the simulations independent of the type of code used, as long as the Hall term is included. In addition, the reconnection rate is independent of the mechanism which breaks the frozen-in flux condition, whether it is electron inertia or grid scale diffusion. The insensitivity to the mechanism which breaks the frozen-in condition is a consequence of whistler waves, which control the plasma dynamics at the small scales where the ions become unmagnetized. The dispersive character of whistlers, in which the phase velocity increases with decreasing scale size, allows the flux of electrons flowing away from the dissipation region to remain finite even as the strength of the dissipation approaches zero. As a consequence, the throttling of the reconnection process as a result of the small scale size of the dissipation region, which occurs in the magnetohydrodynamic model, no longer takes place. The important consequence is that the minimum physical model necessary to produce physically correct reconnection rates is a Hall MHD description which includes the Hall term in Ohm's law. A density depletion layer, which lies just downstream from the magnetic separatrix, is identified and linked to the strong in-plane Hall currents which characterize kinetic models of magnetic reconnection.

Failure of "Guide field" to suppress reconnexion in simulations has been borne out in more recent reports by Shay, Rogers, and Drake [AGU SM02]

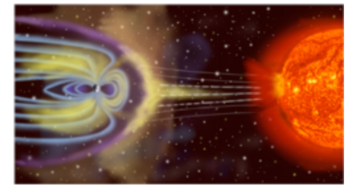
Reconnexion Fields and Flows



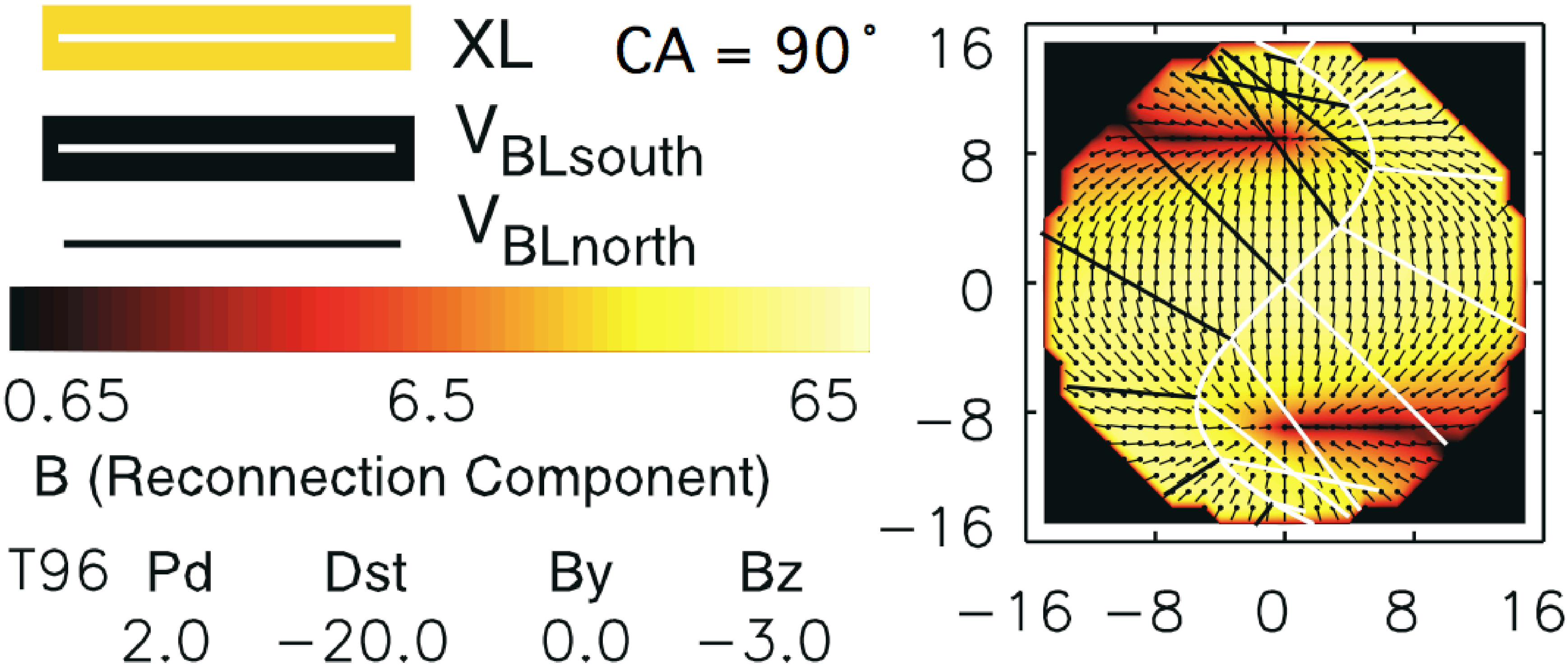
- Cowley and Owen [PSS 1989]
  - Radially divergent sheath flow
  - Plasma flows across MP freely:
  - Pressure balance established inward of BL, where SH plasma pressure drops and MS field increases
  - Assume SH and BL fields equal
    - (MP as rotational discontinuity)
  - Consider HT frame where
    - V_{plasma} // B_{SH}, in SH
    - $V_{plasma} = V_{HT}$, at MP
    - V_{plasma} // B_{BL}, in BL
  - Geometric Flow Construction:
    - Flux tube motion at MP, V_{HT}
    - Plasma motion in V_{SH}, V_{BL}



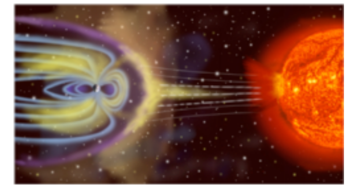
Case of 90˚ Clock Angle (Bz=0)

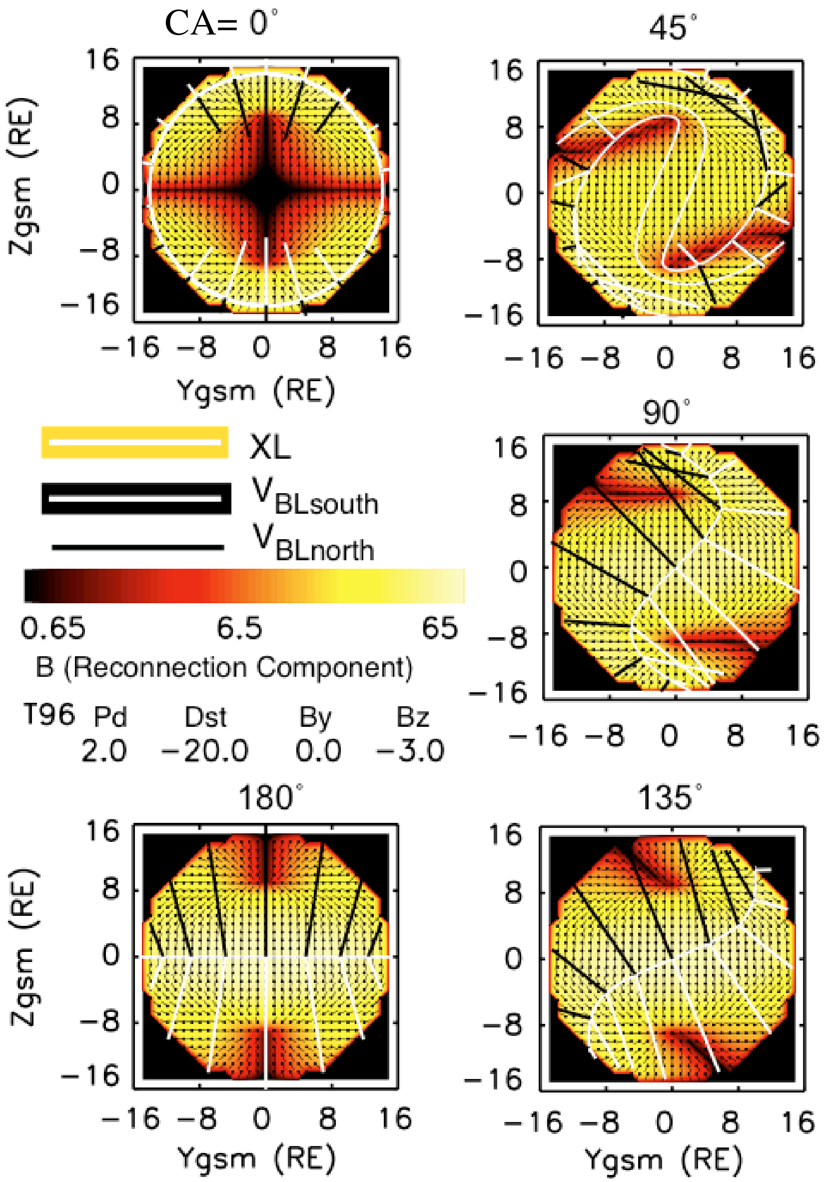


- Allow XL to be a curve rather than a line!
- Plot reconnexion component vs position on m'pause
- Reconnexion component mirror image of anti-parallel ridges
- RC widespread; peak at subsolar point for this case.
- Where/why is reconnexion initiated? Max RC vs max cos(A)?



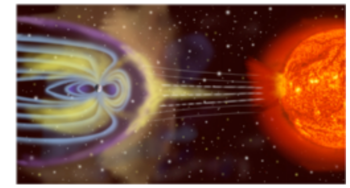
XL as S (By<0) or Z (By>0) Line

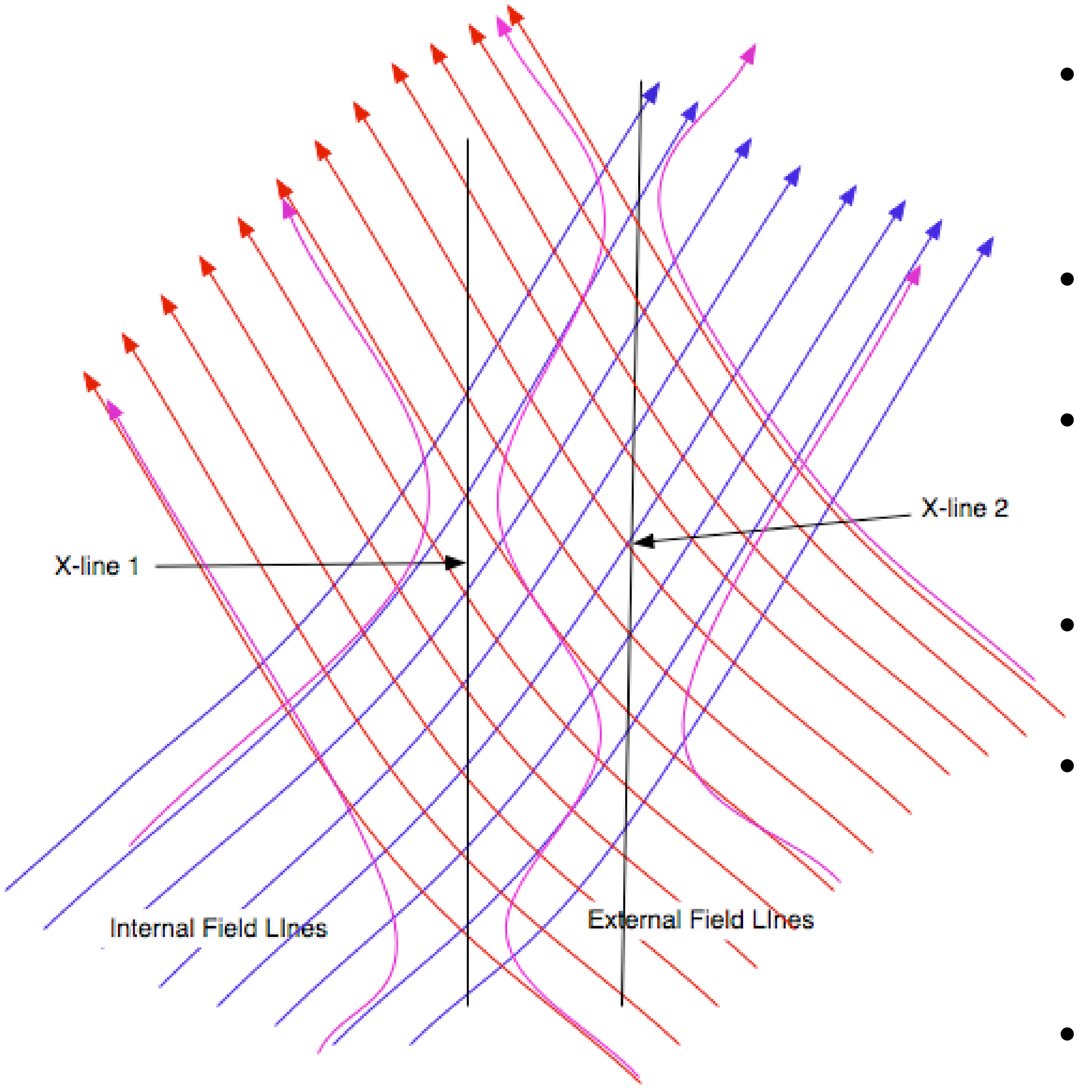




- T96 field model
- Evaluated 0.5 Re inside MP
- Draped magnetosheath field
- Anchor points at point of maximum reconnexion component
- Compute BL plasma flow per Cowley and Owen [PSS 89]
- Results:
  - SBz gives equatorial XL
  - By curves the XL up over cusp
  - NBz w/ By gives multiple wraps of XL over cusps
  - NBz gives circular XL

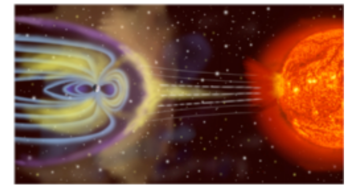
Double XLs and Helical Flux Ropes



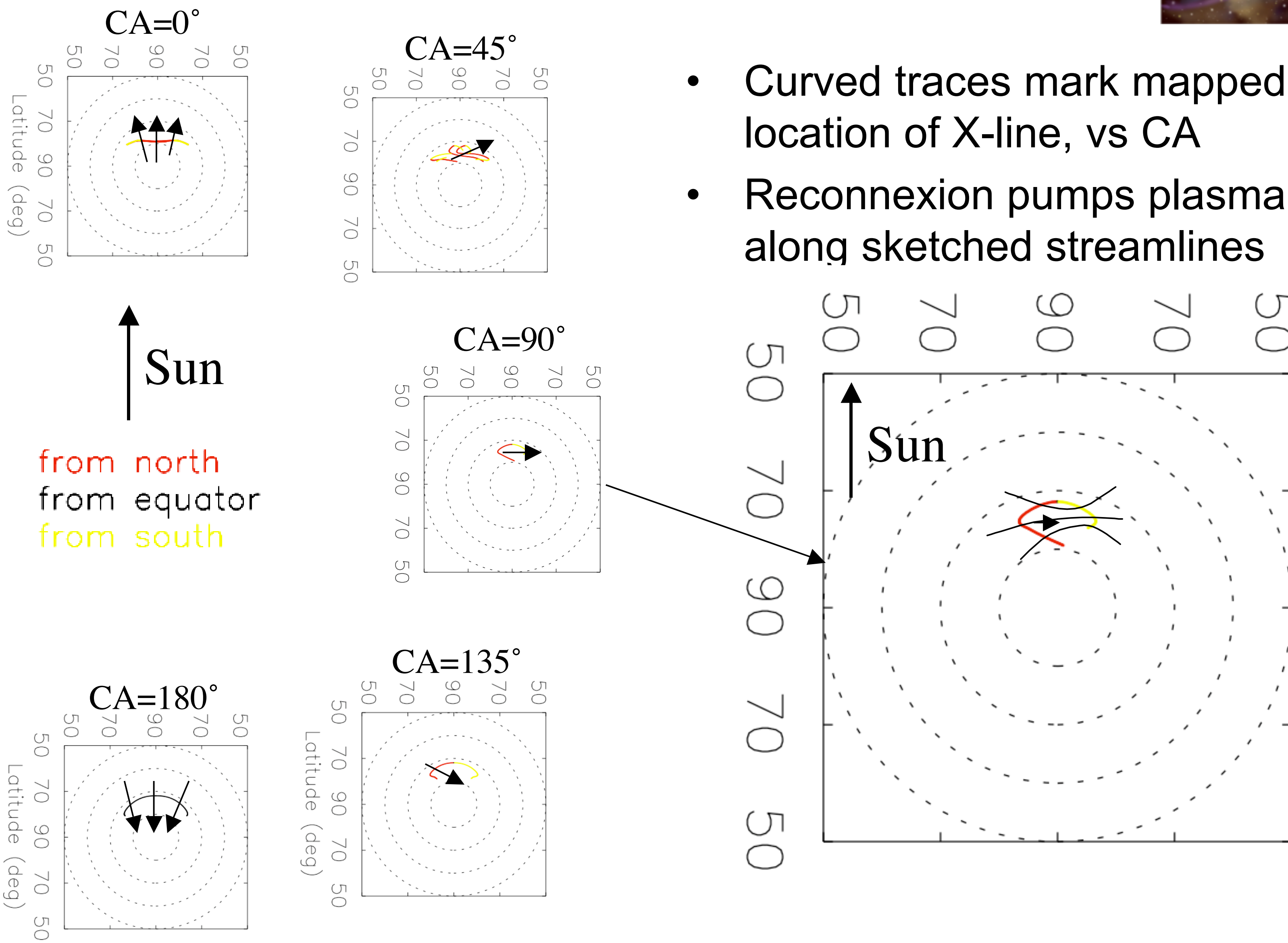


- Multiple wraps of the XL for northerly B tends toward multiple "parallel" X-lines
- If so, flux rope helices will form
- Leads to a relatively decoupled region of interstreaming plasmas
- Ends may connect to either solar wind or ionosphere
- These are seen in simulations of L Lee and in Interball observations of Vaisberg et al. Poster
- Must eventually dissipate by unwinding.

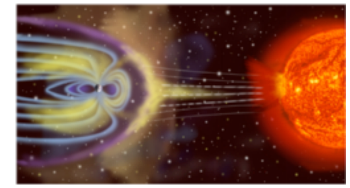
Cusp Footprint and Flow Mapping



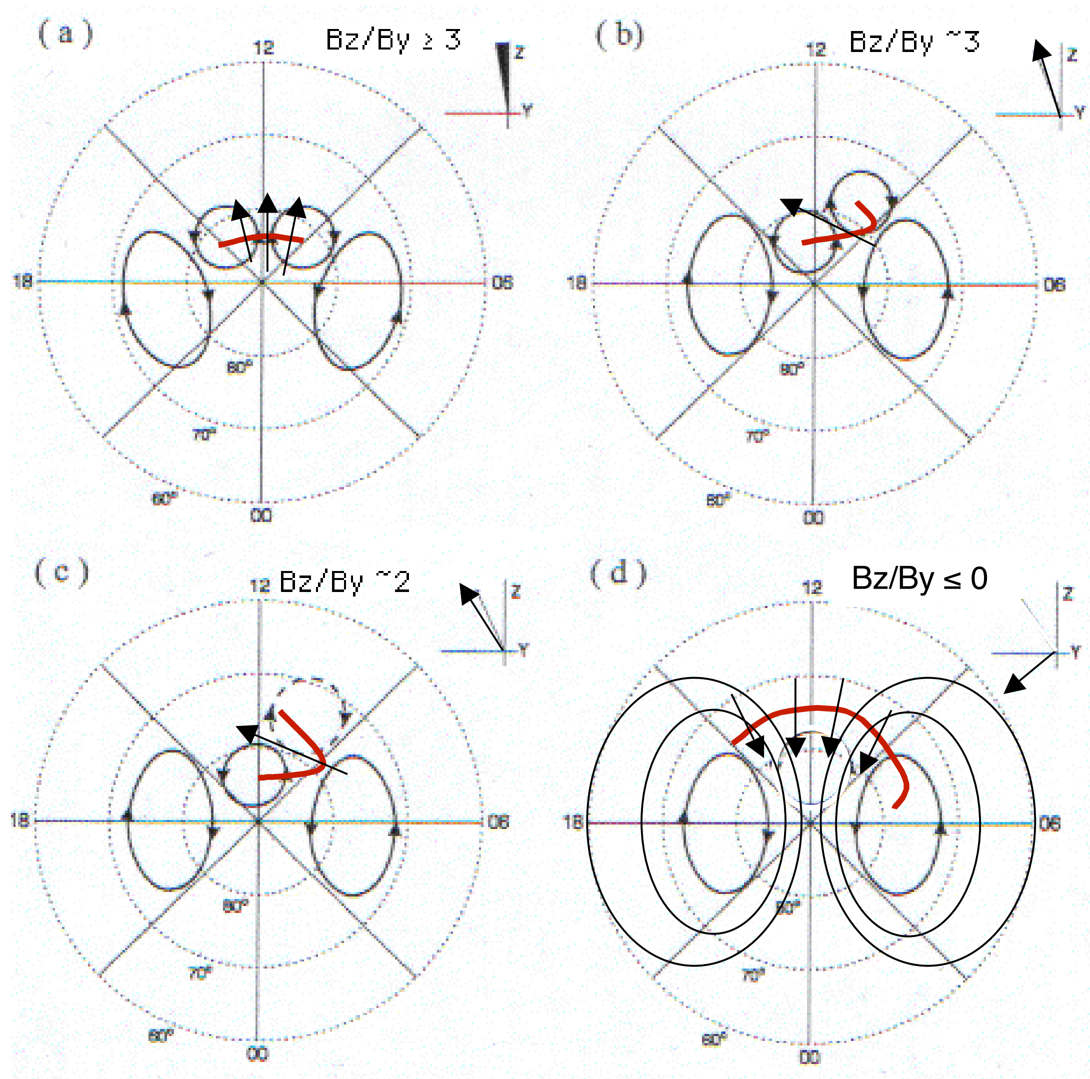
- Curved traces mark mapped location of X-line, vs CA
- Reconnexion pumps plasma along sketched streamlines



Ionospheric Flow Observations

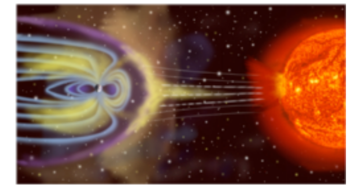


- NBz study
  - Distinct four cell pattern suggests both high latitude and low latitude reconnexion
  - Clock angle variations near Z (NBz) consistent with tilting of reconnexion pump.
  - Greater deviation from zero CA couples into the main two-cell pattern
  - Consistent with distributed component reconnexion



Huang et al. JGR 2000, p.27095

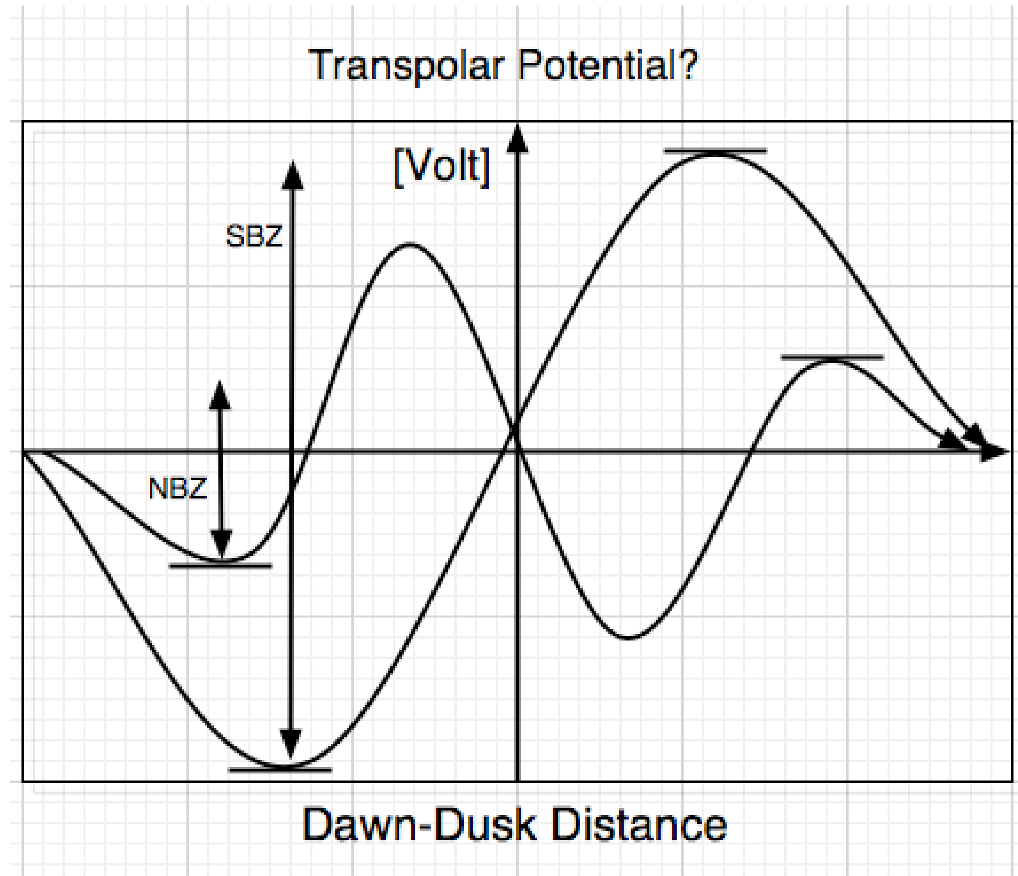
Transpolar Potential vs IMF



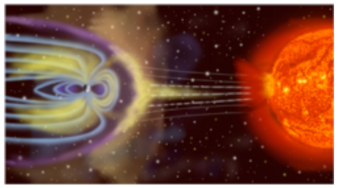
- NBz potential oscillatory
- NBz 4 cell pattern
- Difference of Bz and LLBL cells

- Large TPP, 2 cell pattern?
- Sum of LLBL plus Bz cell

- Clock angle controls the orientation of the reconnexion-driven Bz cell.

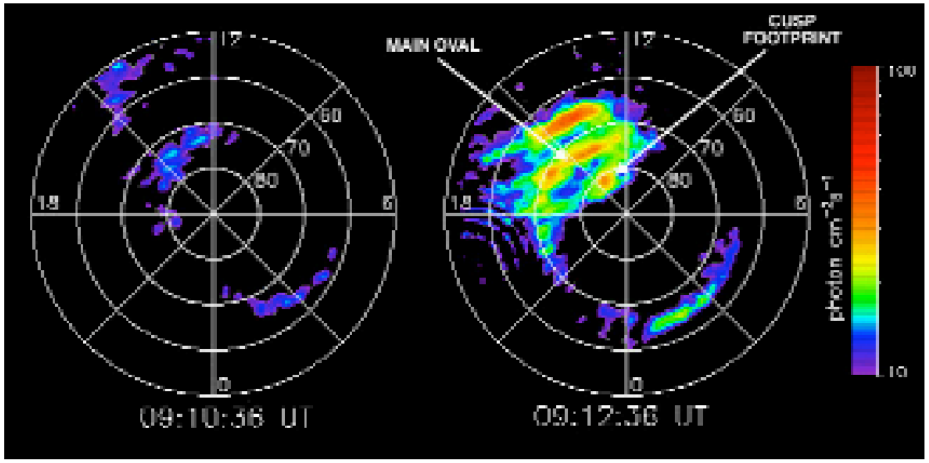


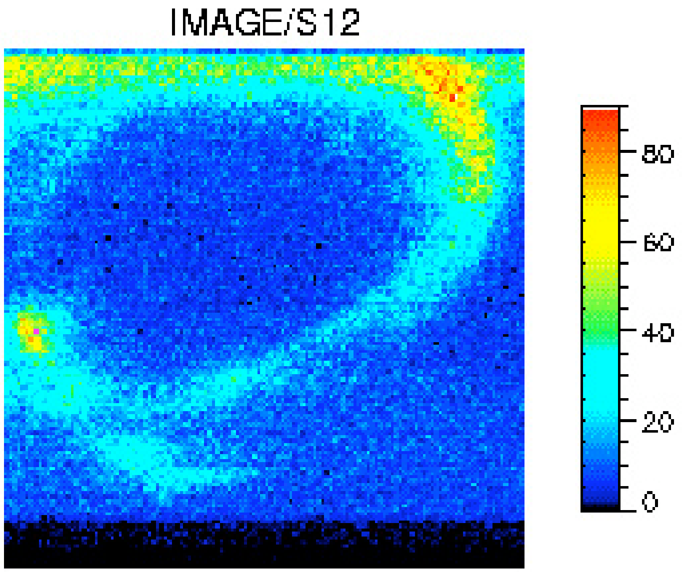
Dayside Q Aurora



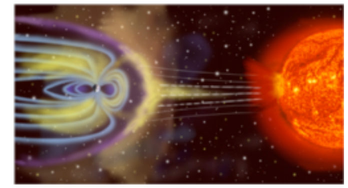
- Earlier arguments for low shear reconnexion:
  - Cowley 1976; Paschmann et al., 1990, 1993, Onsager & Fuselier,1994,Chandler et al. 1999.
- Recent studies feature simultaneous multiplicity of cusp = auroral forms
  - Proton aurora from IMAGE reveals multiple simultaneous magnetosheath precipitation features
  - Recent DMSP observations also interpreted as “multiple” cusp.
- Bright spot for cusp in NBz
- Q auroral tail associated with NBz and By changing sign through 0.
- Interpret as ionospheric reconnexion jet. Extension equatorward of oval indicates solar wind entry to LLBL

Fuselier et al. 2001, 2002 IP
Burch et al. 2002 IP





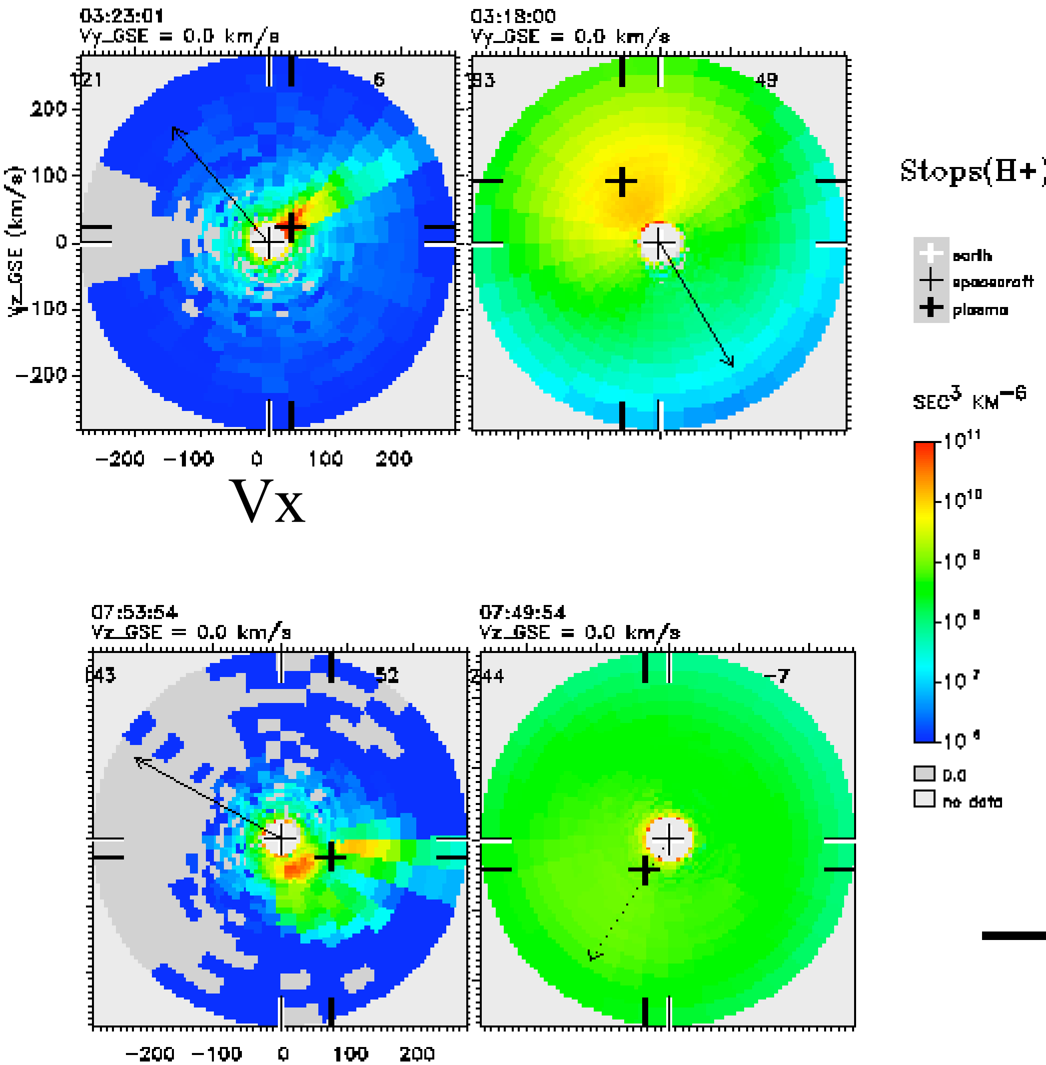
Subsolar Sunward Plasma Flows



03/20/01

Vz

GSE



Vx

04/02/02

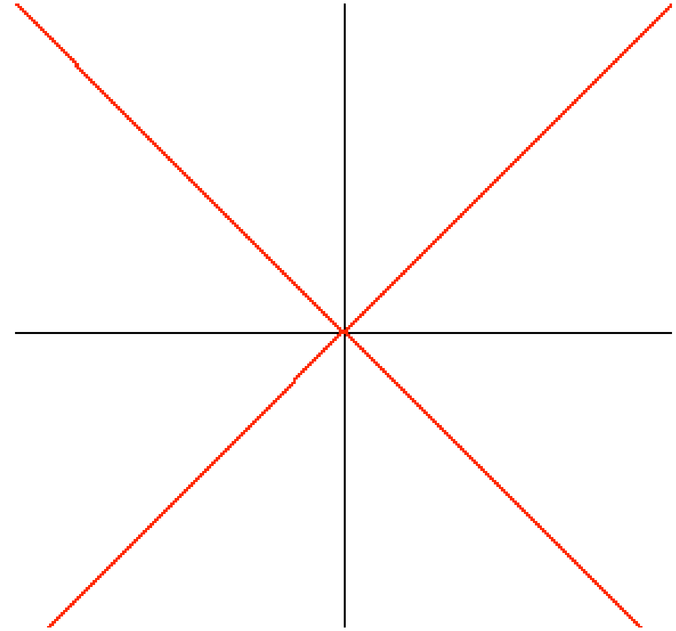
Vy

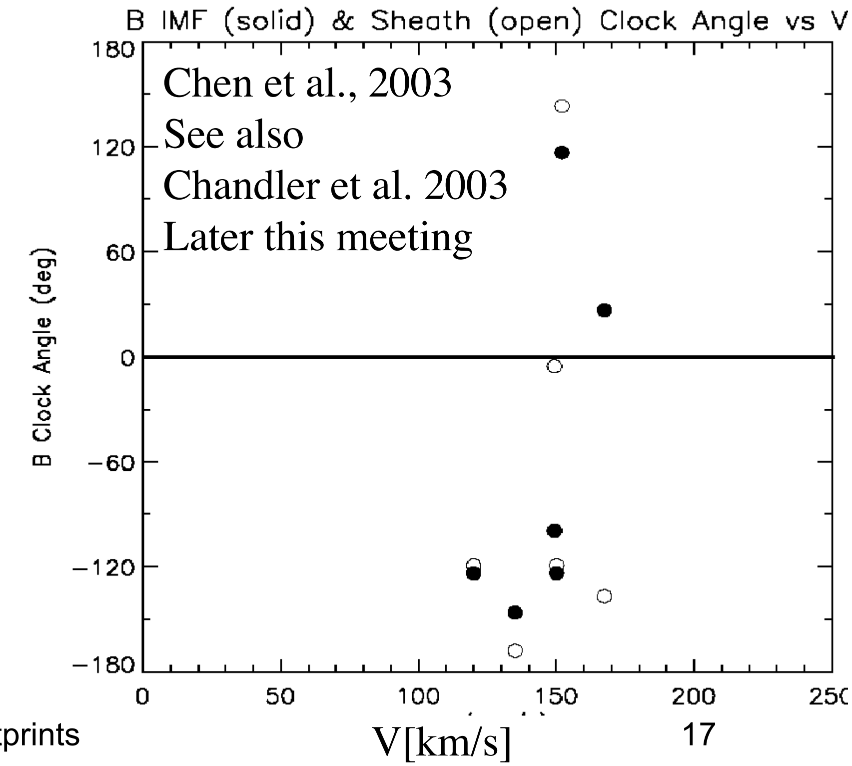
Vx

Sun

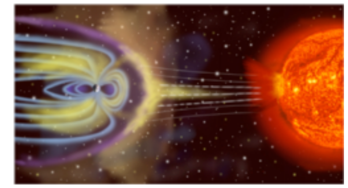
Conclusions

- XL is an S or Z curve
  - Local rates control potential drop
  - Helical island flux ropes follow from multiple XLs
- Consistent with ionospheric “throat” footprints
  - Curvature of XL concentrates plasma flow -> proton aurora.
- Consistent with low TPP but strong dayside activity
- Consistent with widespread reconnection at all clock angle->
- What controls local reconnexion rate and resultant distribution?
  - MMS





Footprints of Dayside Reconnexion



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The hypothesis that reconnection occurs along a locus where merging fields are antiparallel is both intuitively appealing and supported by a number of in situ observations. The loci of antiparallel fields are curves lying on the dayside magnetopause that radiate away from the cusps, equatorward for southward Bz, poleward for northward Bz, and flankward for finite By with east-west sense determined by the sign of By. Yet when reconnection commences at any point along an antiparallel locus, its local X-line is near-normal to that locus, and reconnection cannot extend far along the X-line and remain antiparallel. If the reconnection rate drops precipitously for small deviations from antiparallel fields, it must then be limited to one or more short X-line(s) extending across the antiparallel locus, limiting the transpolar potential that can be developed. If, instead, the reconnection rate is proportionate to the magnitude of the antiparallel field component (the reconnecting component) at any point, then reconnection will extend away from the antiparallel locus along an X-line curve that we have integrated and which extends for great distances across the magnetopause. Recent observations and simulations suggest that the reconnection rate is insensitive to the angle between the merging fields, or equivalently, to the "guide field" component. We explore the consequences of this for the configuration of the X-line, suggesting a synthesis of the antiparallel and component reconnection hypotheses. An S-or Z-shaped X-line, depending on By, is the simplest general case and consistent with the By dependence of ionospheric convection features. Multiple X-lines form when more than one site initiates reconnection, as for northerly Bz. The result of multiple active X-lines must be a region of helical fields between any nearby pair of X-lines, forming an isolated region of mixed internal and external plasmas. Newly linked flux tubes continue to be peeled off from the X-lines on either side of the helical region. These features are seen in certain MHD simulations and evidence of them has also been found in Interball plasma observations.

- Outline
  - Antiparallel reconnexion
  - XL orientation problem
  - Component reconnexion
  - Reconnexion rate
  - Transpolar potential
  - Guide field effects
  - XL as Z or S line
  - Double XLs and flux helices
  - Cusp footprints
  - Q aurora
  - Conclusions